NOAA's **aquarius** America's Innerspace Station

Pipeline to the Coral Reefs

Focus
Effect of upwelling on nutrient availability to coral reefs

Grade Level
9-12 (Earth Science)

Focus Question
How is the condition of coral reefs affected by physical oceanography phenomena?

Learning Objectives
Students will be able to define and describe internal waves and explain their influence on coastal upwelling.

Students will be able to analyze and discuss the effect of high nutrient concentrations caused by upwelling on the overall condition of Florida coral reefs.

Materials
Activity 1 – Stratification and Internal Waves

(One set for a demonstration or one set per group of 3 to 4 students)

- One 2-liter colorless soda bottle
- One liter of water
- Food coloring
- One liter of colorless vegetable oil or baby oil
- Funnel

Activity 2 – Upwelling Models

(Per group of 3 to 4 students)

- Clear rectangular container (plastic shoebox or aquarium)
- Metric ruler
- Marker
- Styrofoam cup
- Snap-type clothes pin
- 250-ml beaker
- 250-ml graduated cylinder
- Food coloring, stirring rod, tap (hot and cold water)
- Masking tape
- Thermometer
- Pencil

Audio/Visual Materials
None

Teaching Time
Two or three 45-minute class periods

Seating Arrangement
Groups of 3 or 4 students

Key Words
Benthic
Internal wave
Macroalgae
Nutrients
Pycnocline
Thermocline
Tidal bore
Upwelling

Background Information
Aquarius is an undersea laboratory owned by the National Oceanic and Atmospheric Administration (NOAA). Its purpose is to support research on oceans and coastal resources by allowing scientists to live and work on the seafloor for extended periods of time. *Aquarius*

is presently deployed three and a half miles offshore in the Florida Keys National Marine Sanctuary. It operates 62 feet beneath the surface at Conch Reef. Missions typically last 10 days and aquanaut candidates undergo five days of specialized training before each mission starts. Visit http://www.uncw.edu/aquarius/ for more information, including a virtual tour of the *Aquarius* laboratory.

Aquarius missions are focused on understanding our changing ocean and the condition of coral reefs. In 2001, Dr. James Leichter (Woods Hole Oceanographic Institution) conducted an *Aquarius* mission to study how nutrients move near the coral reef surface near the *Aquarius* habitat site. The mission summary explains the following:

"Coral reefs need nutrients to grow and thrive, just as all living things need nutrition to grow and thrive. The major question addressed by the current *Aquarius* mission scientists is: Where do the nutrients come from that support the growth of corals? Results from this work address an important management issue in south Florida related to water quality and the potential problems of nutrient pollution. It is generally understood that coral reefs thrive in tropical waters that are typically low in nutrients. But the picture that is emerging for reefs in Florida is that the story is much more complex."

At the *Aquarius* web site (http://www.uncw.edu/aquarius/archive/2001/6_2001/expd.htm), you can read the entire project summary for this mission, view aquanaut biographies and expedition journals, and run an internal wave simulation.

A major goal of coastal oceanography and marine ecology is to understand the links between physical oceanographic phenomena and benthic community dynamics. Internal waves can affect coral reefs by moving deeper, nutrient-rich cold water up onto the reef. This phenomenon is known as internal tidal upwelling. This occurs as internal tidal bores, generated at the leading edge of the advancing internal tide and by breaking internal waves, force fronts of cool, nutrient-rich subsurface water on the reef. Breaking internal waves may mix nutrient-rich cold water from below the thermocline into nutrient-poor surface waves, causing an upwelling event.

Scientists working at *Aquarius* are interested in studying the temporal and spatial variability of this pattern and the impact on the Florida Keys coral reefs. Understanding how nutrients are delivered to the reef system is essential to understand the function of coral reef ecosystems, and what efforts might be required to help sustain healthy coral reefs. Dissolved nutrients that reach coral reefs in the Florida Keys may arise from a variety of sources, but the story is not just about nutrient concentrations. The availability of nutrients to coral reef organisms is governed both by nutrient concentrations and water flow. So, to estimate nutrient inputs to the reef we need to know both concentrations and flow speeds close to the bottom, and how these vary with time. Recent research has shown that cool, nutrient-rich water is transported onto Florida Keys reefs by internal bores and is a potentially important source of nutrients. Internal bores are generated by internal tides and breaking internal waves, and their arrival on reef slopes is accompanied by rapid fluctuations in near-bottom water temperature and density, as well as strong upslope flows.

Physical oceanography is the study of the physics of the ocean and the linkages between the ocean and the atmosphere. Physical oceanographers study the distribution of properties such as temperature, salinity, and the density of seawater. These properties are used to help distinguish and track one water mass from another. Density is the amount of mass per volume and is expressed as grams per cubic centimeter (g/cm^3). Density in the ocean varies based on temperature, salinity, and pressure.

Physical oceanographers are also interested in studying the motions of the ocean in response to the forces that include waves, currents, and tides. Waves are caused by a variety of forces such as wind, storms, density gradients within the ocean, or submarine disturbances. Tides are waves with very long periods and wavelengths and are caused by the gravitational attraction of the sun and moon on the Earth. Currents at the surface are caused by wind patterns; while deep ocean currents are caused by density differences as when warmer, lower salinity water rises or a colder, higher salinity water sinks.

Waves can also be created underwater when a water mass of lower density overlies a water mass of higher density. These underwater waves are "internal waves." Internal waves can be generated whenever water forms layers due to differences in density. Differences in density can be caused by temperature: for example, when warm surface waters overlie colder deeper waters. The gradient in temperature from the surface to deeper waters can be gradual or steep, depending upon how much mixing occurs. Often, there is a distinct layer that forms that defines dramatically different temperatures (and thus densities) over a relatively short distance. This area of rapid change in temperature is called the thermocline. Density layers can also form as a result of differences in temperature and salinity between water masses. Pycnocline is the general term that defines the boundary between different water masses due to differences in density.

Internal waves behave just like surface waves as they enter shallow water and interact with the seafloor. They slow down, their wavelength is reduced, and eventually their wave height increases until they break. Because of their long wavelengths, internal waves generally break on the outer part of the continental shelf. Internal waves typically have 5 to 8-minute periods and wavelengths of 0.6 to 0.9 km with heights of 100 meters (visit http://pao.cnmoc.navy.mil/educate.neptune/quest/wavetide/waves.htm for more information about waves).

Water over the crest of the internal waves shows ripples, while water over the trough of the internal wave is quiet. Surface bands can be seen to move along the sea surface as the internal waves pass below. The causes of internal waves are still an active area of research. Possible explanations for internal waves include:

- the period of some internal waves approximates the period of the tides;
- water movement due to tides over an uneven bottom can cause instability and create waves;
- the friction of a water mass slipping over another may cause a wave; and
- low pressure storms may depress the pycnocline.

In this activity, students will make their own internal wave, and construct a model of upwelling.

Learning Procedure

1. Prepare thermometers and plastic containers for modeling upwelling events:
   - Attach a thermometer to a ruler using thin wire. The thermometer should be securely fastened, perpendicular to the ruler, and as close to one end of the ruler as possible.

- Use a metric ruler to mark 2-cm intervals on the clear plastic shoeboxes or aquaria to record temperatures at different depths after you create a current. Use the marker to mark the lines on one of the long sides of the container.

2. Modeling an internal wave (this may be done as a demonstration by the teacher, or by groups of 3 - 4 students):

- Remove the colored label from a soda bottle and remove the colored band from the bottom of the soda bottle (soaking in hot water aids in removal).
- Use a funnel to fill the soda bottle with approximately one liter of water.
- Add a few drops of food coloring. Swirl to mix.
- Using the funnel, add approximately one liter of oil to the soda bottle.
- Hold the bottle at the neck and base and tilt to see the internal wave motion.

3. Discuss density differences between the water and oil and the relationship of these differences to stratification.

4. Have each student group create a model of Upwelling Events:

- Pour about 3 liters of warm tap water (about 50°C) into the container. The water level should be about 2 cm below the top of the container.
- Using a clothes pin, clamp the empty Styrofoam cup to the edge of the container opposite the side with the depth interval marks. Use the point of a pencil to poke a 1 - 2 mm diameter hole in a Styrofoam cup. The hole should be approximately 5 cm from the cup's bottom and under the surface of the water. Take the cup out of the water and place a strip of masking tape over the hole.
- Place two ice cubes and 100 ml of cold tap water in a beaker. Add 3 drops of food coloring to the cup of cold water. Stir until the food coloring mixes completely with the water. Slowly, pour the colored, cold water into the Styrofoam cup. Carefully remove the tape from over the hole.
- Observe the pattern of the cold water as it moves out of the cup into the aquarium water.
- Diagram the water movement on the illustration.
- Use the thermometer attached to the ruler to record the temperature at 1 cm depth intervals. Take the readings at the marked end of the container as the colored water begins to approach by lowering the thermometer 1 cm at a time.
- Construct a graph of the temperature change with depth. Label the thermocline.

5. Have students write a short report describing how internal waves, stratification, and upwelling phenomena might affect coral reefs. Lead a group discussion of students' reports. Students should realize that water movement affects reefs in a variety of ways, including:

- transport of larvae and/or gametes;
- bringing nutrients into the reef system from other areas;
- removing particulate materials from the reef system (thus reducing potentially available food to reef inhabitants);
- modifying thermal conditions by bringing warm or cold water masses into the reef system; and
- causing turbulence, which favors coral species that are adapted to turbulent conditions.

The 2001 *Aquarius* mission led by Dr. Leichter focused particularly on water movements that could transport nutrient rich water from the deep Gulf Stream onto coral reefs of the Florida Keys. The mission summary explains that while Gulf Stream waters are typically low in nutrients, beneath the surface of the Gulf Stream (sometimes as shallow as 100 feet deep) lies a region where the warm low nutrient water transitions to a colder nutrient-rich realm. Nutrients in these deeper waters concentrate as a result of natural processes. Few people are aware of the vast nutrient pool that lies just offshore of the reefs that is part of the deeper Gulf Stream waters, and mechanisms that bring it to the reef have not been well-studied.

The BRIDGE Connection

www.vims.edu/bridge/ – Click on "Ocean Science" in the navigation menu to the left, then "Ecology," then "Coral."

The "Me" Connection

Have students write a short essay on how physical oceanographic processes might be directly important to their own lives.

Connections to Other Subjects

Mathematics, Life Science, English/Language Arts

Evaluation

Individual data analyses and participation in group discussions provide opportunities for assessment.

Extensions

Visit http://www.uncw.edu/aquarius/ to learn about other *Aquarius* missions and activities.

Have students work in teams on the WebQuest entitled Coral Reef Rescue at the following web site:

http://oncampus.richmond.edu/academics/as/education/projects/webquests/coralreefs/

Resources

http://pao.cnmoc.navy.mil/educate.neptune/quest/wavetide/waves.htm – Naval Meteorology and Oceanography Command web site with information on waves and tides

http://www.reefnet.org/ - Note articles by scientists and conservationists, including recent discoveries, information about how individuals began their careers, interviews about their work, and well-written accounts of what it is like to work as a marine scientist.

http://state-of-coast.noaa.gov/bulletins/html/crf.html - NOAA's State of the Coastal Environment: The Extent and Condition of U.S. Coral Reefs. 1998. S. L. Miller and M. Crosby

http://www.reefcheck.org – Reef Check: How to participate in coral monitoring

http://www.coris.noaa.gov/ - NOAA's Coral Reef Information System (CORIS) is designed to be a single point of access to NOAA coral reef information and data products, especially those derived from NOAA's Coral Reef Initiative Program. CoRIS will evolve and grow in the months ahead to encompass an ever-widening array of product and information offerings.

http://www.ocean98.org/cacoast2.htm - Upwelling

National Science Education Standards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Motions and forces
- Interactions of energy and matter

Content Standard C: Life Science

- Interdependence of organisms
- Matter, energy, and organization in living systems

Content Standard F: Science in Personal and Social Perspectives

- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

Activity developed by Julie Lambert

Student Handout

Upwelling Events
Student Instruction Sheet

To prepare the thermometer and depth intervals:

1. Attach a thermometer to a ruler using thin wire. The thermometer should be securely fastened, perpendicular to the ruler as close to one end of the ruler as possible.
2. Use a metric ruler to mark 2-cm intervals on the container to record temperatures at different depths after you create a current. Use the marker to mark the lines on one of the long sides of the container.

To make a density-driven current and simulate an upwelling event:

3. Pour about 3 liters of warm tap water (about 50°C) into the container. The water level should be about 2 cm below the top of the container.
4. Using a clothes pin, clamp the empty Styrofoam cup to the edge of the container opposite the side with the depth interval marks. Use the point of a pencil to put a small hole in a Styrofoam cup. The hole should be approximately 5 cm from the cup's bottom and under the surface of the water. Take the cup out of the water and place a strip of masking tape over the hole.
5. Place two ice cubes and 100 ml of cold tap water in a beaker. Add 3 drops of food coloring to the cup of cold water. Stir until the food coloring mixes completely with the water. Slowly, pour the colored, cold water into the Styrofoam cup. Carefully remove the tape from over the hole.
6. Observe the pattern of the cold water as it moves out of the cup into the aquarium water.
7. Diagram the water movement on the illustration.
8. Use the thermometer attached to the ruler to record the temperature at cm depth intervals. Take the readings at the marked end of the container as the colored water begins to approach by lowering the thermometer 1 cm at a time.

Depth (cm)	Temperature (°C)

9. Construct a graph of the temperature change with depth. Label the thermocline.